Institute of Technical Physics

Beam-Riding Simulation and Diagnostics for Beamed-Energy Vehicles

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Will my engine ride the beam?

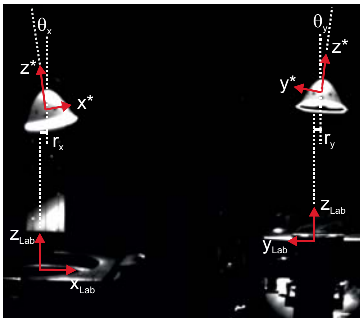
Perfect Beam-Riding

- Restoring lateral momentum coupling

$$c_{m,i} = \frac{\Delta p_i}{E_L} \approx \frac{m \cdot \Delta v_i}{E_L} = b^{(m)} \times x_i,\ b^{(m)} < 0$$

- Restoring angular momentum coupling

$$c_{L,i} = \frac{\Delta L_i}{E_L} \approx \frac{J_{ii} \cdot \Delta\omega_i}{E_L} = b^{(L)} \times \vartheta_i,\ b^{(L)} < 0$$



Free flight experiment, stereoscopic view

Lateral$^{(m)}$-angular$^{(L)}$ Coupling

$$\begin{pmatrix} b_i^{(m)} & b_{\vartheta,i}^{(m)} \\ b_i^{(L)} & b_{\vartheta,i}^{(L)} \end{pmatrix} \begin{pmatrix} r_i \\ \vartheta_i \end{pmatrix} \approx \begin{pmatrix} c_{m,i} \\ c_{L,i} \end{pmatrix} = \frac{1}{\overline{P}_L} \begin{pmatrix} \overline{F}_i \\ \overline{M}_i \end{pmatrix} \approx \frac{1}{\overline{P}_L} \begin{pmatrix} m \cdot \ddot{r}_i \\ J \cdot \ddot{\vartheta}_i \end{pmatrix}$$

- Linearization of momentum coupling: $b_i^{(j)}$: craft-specific constants
- Quasi-continuous approximation: Equations of motion

Requirements for Beam-riding

Necessary condition

$$\delta = \left[\frac{b_i^{(m)}}{m} - \frac{b_{\vartheta,i}^{(L)}}{J}\right]^2 + 4\frac{b_{\vartheta,i}^{(m)}}{m}\frac{b_i^{(L)}}{J} \geq 0$$

Sufficient condition

$$\frac{b_i^{(m)}}{m} + \frac{b_{\vartheta,i}^{(L)}}{J} \leq -\sqrt{\left(\frac{b_i^{(m)}}{m} - \frac{b_{\vartheta,i}^{(L)}}{J}\right)^2 + \frac{b_{\vartheta,i}^{(m)}}{m}\frac{b_i^{(L)}}{J}}$$

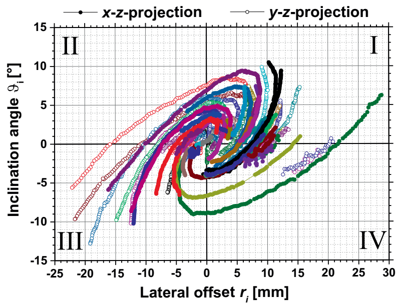
Restoring momenta exceed lat.-ang. coupling.

Implications

- Assumption of 2D approach
- Dependency on BEP mass, CMS position, momentum of inertia
- Independency on laser power

Example - Parabolic Lightcraft

Lateral-angular Motion



Trajectories from free flight experiments

Motion Characteristics

Spiral-formed trajectories

$$\begin{pmatrix} r(t) \\ \vartheta(t) \end{pmatrix} = exp(\kappa t) \begin{pmatrix} \hat{r}\, cos(\omega t + \varphi) \\ \hat{\vartheta}\, cos(\omega t + \varphi + \Delta\varphi) \end{pmatrix}$$

Oscillation period T = 0.78 s
Damping constant $\kappa = 0.97\ s^{-1} > 0$

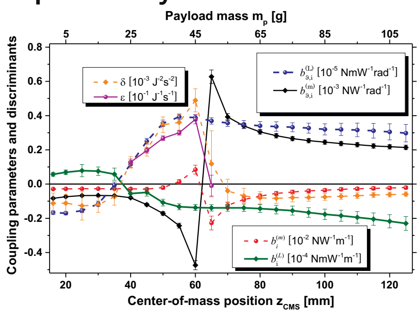
Specific Matrix of Flight Dynamics

$$\begin{pmatrix} b_i^{(m)} & b_{\vartheta,i}^{(m)} \\ b_i^{(L)} & b_{\vartheta,i}^{(L)} \end{pmatrix} = \begin{pmatrix} -0.4\ N/(MW \cdot mm) & -2\ N/(MW \cdot deg) \\ +20\ mN \cdot m/(MW \cdot mm) & -70\ mN \cdot m/(MW \cdot deg) \end{pmatrix}$$

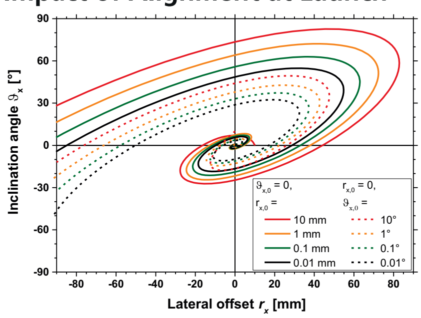
$$\delta = -1.27 \cdot 10^{-4}\ J^{-2} s^{-2} < 0$$

Failure of beam-riding

Impact of Payload Mass

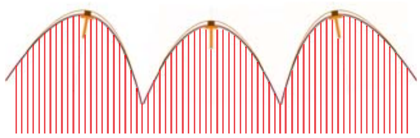


Impact of Alignment at Launch



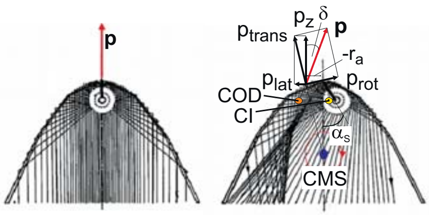
Solution strategies

Geometric Optimization



Cross-section of honeycomb-like thruster array with enhanced lateral coupling

Movable Detonation Center

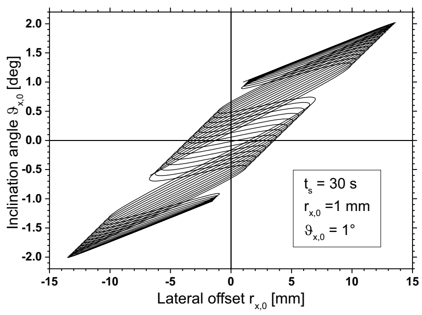


Shift of the detonation center (COD) by tilt of the ignition pin inside the lightcraft

Alternative Solutions

- Spin-stabilization (Myrabo)
- Decoupling of optics and nozzle (Rezunkov)
- Dynamic adjustment of laser beam position (Takahashi)

Theoretical Solution



Knowledge for Tomorrow

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